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## TRANSLATION

NEW LOW VOLTAGE SOURCES OF  
VACUUM ULTRAVIOLET

By

Ye. M. Akimov

## FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE  
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NEW LOW VOLTAGE SOURCES OF VACUUM ULTRAVIOLET

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New Low Voltage Sources of Vacuum Ultraviolet

by

Ye. M. Akimov

Introduction.

Vacuum ultraviolet is called the optical emission with a wave length of from 1850 Å to several angstrom units, filling-in in the scale of electromagnetic waves the interval between ordinary ultraviolet and the zone of soft x-rays. From the viewpoint of suitability to excite vacuum ultraviolet all optica emission sources can be divided into the following groups:

1) sources, principally unsuitable for this purpose (e.g. all types of incandescent tubes, because their temperature is totally insufficient, as to give a noticeable emission in the interesting us zone of the spectrum);

2) sources, not used until now for vacuum spectroscopy purposes, but principally suitable for this purpose (activated AC arc, particularly in spark regime [1], high frequency spark [2], this and another in an atmosphere transparent for vacuum ultraviolet gas - nitrogen, hydrogen or helium. The spectrum in this case is always limited by the shortwave transparency maximum of the gas used [3] );

3) sources, which are for operation in vacuum as well as in other zones of the spectrum (DC arc and condensed spark in an atmosphere transparent for vacuum ultraviolet [4-7], as well as various types of low pressure gas discharge: glowing, arc, high frequency electrodeless discharge, discharge with hollow cathode [8-13] );

4) Sources, specific for vacuum spectroscopy (vacuum arc [14, 15], vacuum spark [16-18], condensed discharge in capillary [19-21]. In recent years was obtained and used for vacuum spectroscopy a sliding spark in vacuum [22, 23] );

5) a powerful source of a continuous spectrum in vacuum ultraviolet appears to be

the emission of electrons in the synchrotron, when their energy reaches hundreds of millions of electron-volts [24,25]. In this report are given results of investigations involving the creation of new low voltage sources of vacuum ultraviolet.

#### Vacuum Arc

Vacuum arc, a DC arc, burning in vapors of electrodes, placed in evacuated space, was used for the excitation of spectra preferably on the early stage of development of vacuum spectroscopy [14,26-28]. In this source are excited spectra of neutral and once ionized atoms [29]. The vacuum arc gives quite narrow lines, and that is why it was used in investigations on accurate determination of wavelengths of spectral lines [30]. The features of the phenomena observed in vacuum arc compel to assume, that it is substantially distinguished by the nature of the elementary processes taking place in it from the electric arc, burning in a gaseous medium. The sole source of the material for maintaining the discharge is the cathode, which principally destroy ed in the process of operation. At the same time the liberation of energy is many ti mes greater than its liberation on the cathode. Specially conducted experiments show ed, that in vacuum arc from the cathode comes out a stream of particles of enormous velocity - more than  $10^6$  cm/sec [31]. Such velocity cannot be explained by the high temperature of the cathode spot, because the latter is totally insufficient for this [32]. As shown by experiments with introduction into the discharge space of a third electrode-collector [41], the particles flying out from the cathode have a negative charge; it was possible to almost fully collect same in this collector (plate), feed ing to it a 1000 v potential positive with respect to the arc electrodes.

To produce a simple, reliable and safe in handling source of vacuum ultraviolet, we carried out a series of experiments with DC-vacuum arc. Molybdenum glass was used to prepare a special discharge tube, the arrangement of which allowed by turning a slide to very smoothly change the distance between the electrodes. The electrodes were fed a constant voltage of 220 v. After many efforts to obtain a continuous hot

at low currents (5-10 amp) vacuum arc we arrived at a conclusion, that for its stable burning in case of using electrodes from material with high melting point a strong local heating of the cathode is needed.

Thanks to relatively low heat conductivity and very high melting point strong local heating can be easily attained on a carbon cathode. The high temperature of the cathode, apparently, plays a double role in maintaining the discharge: a) it aids in evaporation of cathode material, b) assures greater thermionic emission. Since the role of the anode in the discharge is insignificant, it is faced by only one requirement - it should be a conductor of electricity.

In our experiments the discharge tube was evacuated to a pressure of  $10^{-3} - 10^{-4}$  mm Hg. The arc was ignited by smoothly separating the initially adjoining electrodes. The current in the arc was 5-7 amp. Arc burning as result of heating the electrodes and the liberation of gas from them connected with it was accompanied by a rise in pressure in the discharge tube, which in turn led to ignition of the arc gas discharge.

Consequently before each experiment the electrodes were degasified by heating same with the aid of the very same vacuum arc. At the time of arc burning under the effect of strong bombardment with particles coming out from the cathode the anode becomes rapidly heated, copper or iron anode weighing about 5 g, attached to a molybdenum inlet, it transforms quite rapidly into a droplet of molten metal. An increase in distance between the electrodes enabled to attain a voltage drop on them to 80 v, whereby the tungsten anode (rod with  $\varnothing$  of 2 mm) glowed blindingly bright, its temperature was close to the melting point, and the edges melted away, (Flashed off).

And so, a stable vacuum arc at low currents (5-7 amp) can be obtained between the carbon cathode and the anode from any given high melting material by smoothly separating initial contiguous electrodes. It must also be mentioned, that a DC-vacuum arc burns stably in vapors of zinc, antimony or any other easily melting metal, the latter is introduced for <sup>this</sup> purpose into the depth in the cathode made of a a high

melting material, e.g. steel [14]. The filling burns out rapidly, and the flask of source is coated with a layer of evaporized metal. Such an arc is less suitable for long lasting exposures.

#### Arc Activated in Vacuum

We made an effort to utilize a vacuum activated arc. For this on the basis of a step-up-transformer NOM-10 (10 kv, 400 w) by the ordinary arrangement of Svetnitskiy activator [1] was assembled a high frequency generator. It generated a high voltage, sufficient to pierce the interelectrode space within a fraction of a millimeter in high vacuum. The very same discharge tube was used, as in experiments with DC-arc. The tube was vacated to a pressure of  $10^{-4}$  mm Hg. To feed the basic current component of the discharge on electrodes (metallic or carbon) a 220 v AC voltage was supplied.

If the distance between electrodes was sufficiently small, a weak little spark appeared - result of piercing the interelect-

trode interval by the voltage from the HF generator, but this was not accompanied

with ignition of the arc. But in the presence of a sufficient thermionic emission from the cathode (carbon, intensely heated cathode) the imposition of HF voltage from the standard PS-39 generator on the electrodes at interelectrode intervals of 1 - 2 mm assured reliable ignition of the DC vacuum arc. Power for and ignition of the arc was realized in accordance with the arrangement shown in fig.1. Preheating of the cathode was attained in the DC vacuum arc, after which by cutting off the juice the arc died out. DC voltage was again cut in and the arc "reignited" by connecting the activator. From this experiment comes a conclusion that it is possible to ignite an activated AC arc in vacuum between preheated carbon electrodes. We made an effort, analogous to the above described, connecting to heated in a DC vacuum arc carbon elec-

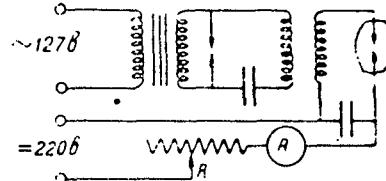


Fig.1. Electric circuit diagram of activated DC arc in vacuum (F-discharge tube).

trodes a voltage from the PS-39 or DG-1 generator. But we have not succeeded in obtaining in this way an AC vacuum arc. Evidently, not every HF team can cause ignition of the arc, consequently the cooling of electrodes is much faster than is permissible to extend the operation of the source.

Upon rapid separation of electrodes to a distance of 2-3 mm and at low currents (5-7 amp) the vacuum arc between carbon cathode and metallic anode burns unstably, the cathode spot shifts continuously over the entire surface of the cathode, the arc is often extinguished. But the application of an HF component according to scheme in fig.1 leads to stabilization of the discharge. the cathode spot localizes only in the frontal surface of the cathode, turned toward the anode. Such an arc can burn uninterruptedly for a period of many minutes.

To work with an activated DC vacuum arc

was prepared a special discharge tube, a schematic drawing of which is given in fig.2.

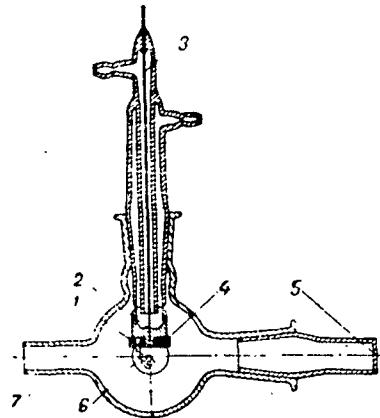


Fig.2. Discharge tube for activated vacuum arc

inlet, soldered in in the second slide, and has no special cooling. Voltage to the anode is fed through the molybdenum inlet.

A change in distance between the electrodes is attained by turning the slide with which the cathode is connected, on account of eccentric fastening the latter relative to the axis of rotation. The arc is ignited by bringing the electrodes to

the point of contact. The discharge tube has attached itself to the vacuum spectrograph DFS6 with the aid of a flexible connection (7) [33], which assure reliable vacuum contact of the tube with the instrument, it can be easily disassembled.

Fig.3. Emission spectrogram of DC-vacuum arc with carbon cathode

It does not appear to be absolutely rigid and allows within small limits to shift the source, which is necessary for the adjustment of the latter. We obtained a number of emission spectrograms of a DC vacuum arc with carbon cathode, activated an non-activated. One of these is shown in fig.3. On the basis of obtained material it is possible to conclude, that in this arc is excited exclusively the material of the cathode-carbon. Upon introduction into the depression in the cathode of various metals (Fe, Cu, Mo, W) it was also impossible to obtain a total spectrum of same.

Contact Spark

To reduce the selective nature of excitation in a vacuum arc and raise its temperature\*, we assembled an electric scheme, allowing to pass through the arc, by discharging capacitor batteries, higher current pulses. An analogous idea has been realized by I.I.Levintov [34] with respect to a DC arc in the air. In contrast to this, we used one and the same source of voltage to feed the arc and to charge the capacitors. The arrangement had a mechanical double throw switch, with the aid of which the battery of capacitors with a capacity of  $90\mu f$  was charged periodically to a voltage of 220 v and then connected to discharge tube electrodes which through the ballast resistance were connected to the very same source. It was revealed during the first connection of this system that the source can also function without the constant current component: upon connection to contacting electrodes (one of which was a carbon one) of a charged capacitor and a spark flickered at the point of their contact. The spark flickered on for several times - sometimes several hundred times- without

any electrode control. It was later established, that this was connected with the springy attachment of electrodes. In case of rigid attachment of electrodes with respect to each other at the point of their contact originates only one discharge pulse, after which a hardly noticeable gap is formed between them, for the piercing of which the voltage used by us was found to be insufficient.

In fig.4 is shown the final electric power diagram of the new source used by us which we intend on calling "contact spark".

(K.I.). This scheme coincides principally with generalized scheme introduced by B.

R.Lazarenko for electrospark treating of (K-mechanical switch, F-discharge tube).

metals [35, 36], differing from it by the presence of a ballast resistance R, which we connected to limit the initial value of the charger current for the battery of high capacity capacitors.

The basic quality of the K.I.(contact spark) is seen by us in the fact, that it is suitable for excitation of spectra in vacuum ultraviolet zone, it can work in high vacuum, as well as in relatively poor rarefaction, at a pressure of  $10^{-2}$  mm Hg and even higher, whereby in the Schumann zone are not excited the bands of  $N_2$  molecule. True, in case of poor vacuum is necessary a thorough insulation of the current carrying inlets in the interior of the discharge tube , otherwise the K.I.pulses (contact spark pulses) are accompanied by gas discharge outbursts and in the spectrum appear lines of the electrode holder material. Self-induction in the discharge circuit of K.I. may be so conveniently small and consequently when working in open air in this source may be obtained a more "rigid" condition , than in the low voltage spark with ignition, where the minimum value of self-induction is principally limited.

K.I. (contact spark) has a series of shortcomings: a)it can operate for a long

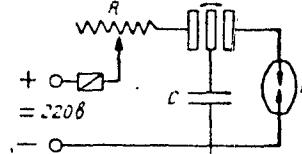


Fig.4. Electric diagram of "contact spark"

\* Footnote for page 6. In strict meaning of the word to speak about the temperature of a vacuum arc of low power is impossible, because in it, apparently, is absent the thermal equilibrium.

time only at a condition, when one (or both) of the electrodes carbon or graphite, discharge between metallic electrodes is accompanied by their rapid destruction; b) frequent adjustment of electrodes is needed to maintain contact between them ; c) during the operation of K.I. in the metallic electrode is formed a recess (iron decomposes faster than other metals), this leads to the necessity during operation of the source to gradually shift the point of contact over the surface of the metal electrode; that is why the discharge tube made by us, in which constant contact between the electrodes was maintained by a very pliable spring, was found to be unsuitable for operation with iron alloys; d) electric power diagram of K.I. contains a mechanical switch, the contacts of which do also gradually decompose under the effect of electro-spark treatment. To prepare contact plates we used tantalum or tungsten.

As shown by experiments with the use of a pulsed photometer, the light pulse of K.I. in the air has a form, typical for low voltage spark: steep rise, broad maximum and "exponential" drop. The duration of the pulse at  $C = 90\mu f$  and  $L = 4\mu$  henries constituted  $80\mu$  sec. which is in excellent conformity with the Thomson formula, if it is assumed, that the pulse lasts for 1/2 of a period. The amount of luminous energy forming in the pulse grows with the rise in capacitor capacitance and voltage, to which they are charged. It also largely depends upon the form of electrode tips - the smaller the magnitude of the contact area of the cone pointed electrodes, the greater is the number, stronger the sound (when working in open air) the greater are the dimensions of the flash. In fig.5 is given a photo of electrode tips at the time of individual pulse in the air between carbon electrodes at  $V = 220$  v,  $C = 500\mu f$ ,  $L = 3\mu$  henries.

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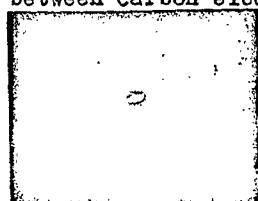


Fig.5. Photo of individual pulse in air between carbon electrodes, given by K.I.

The K.I. spectrum bears a plainly expressed spark nature. In fig.6 is shown the K.I. spectrum between carbon electrodes in air, taken at the very same electrical parameters with the aid of the ISP-22 quartz spectro.

graph, in line with spark spectra from the IG-2 generator in rigid condition ( $L=0$ ) and activated arc. In the visible and close ultraviolet zone K.I. gives a much stronger solid background than a condensed spark. The minimum of blackening in the green part of the spectrum is due to reduced sensitivity in that zone of Panchrome photo plates used by us. A series of experiments was made on the use of K.I. in air for the excitation of spectra of difficultly excitable elements. Their chemical compounds have been introduced into channels drilled in spectrally pure carbon electrodes. These experiments showed, that in K.I. are well excited bromine lines, to a lesser extent - sulfur and phosphorus lines. Utilization of the visible zone of the spectrum for analysis is impossible as result of a strong solid background.

To work with K.I. in vacuum was used a discharge tube, the vertical section of which is shown in fig.7. The tube was made of brass and connected to the spectrograph with the aid of a "mushroom-like" vacuum connection, such a connection was used for the vacuum inlet of upper electrode holder. This holder was also made of metal, and for electric insulation from the body of the discharge tube its side surface was coated with a thick layer of BF-2 glue. Change in distance between electrodes was realized by shifting the outer end of the upper electrode holder in vertical direction. Although the electrode fastening arrangement allowed to use water or air cooling, when working with K.I. at a frequency of ~60 pulses per min. such cooling was not required. The body of the tube was grounded, and to it was attached a cathode made of the investigated material, in the role of anode was used spectrally pure carbon. Destruction of electrodes as result of their "electrospark treating" takes place at such conditions in a considerably lower degree, than in case of their opposite polarity. With the aid of a single prism fluorite vacuum spectrograph SR-33 (model of this instrument is described in [37]), we have photographed spectra of certain metals, excitable with K.I. In the role of photo material was used a photo film sensitized with BM-4 oil. The job was done at  $V = 220$  v,  $L \approx 3$   $\mu$  henries;  $C = 500 \mu f$ . To obtain normal blackenings were

required several hundred pulses. In fig.8 are shown spectrograms obtained under such conditions: copper, aluminum and carbon.



Spectra of iron and copper, excited in K.I. can be used in role of comparison spectra: the wavelengths of spectral lines of these elements in the vacuum zone have been measured with high accuracy [38-40]. An effort was made to use K.I. for purposes of spectrally analyzing ferrous alloys for sulfur and phosphorus. As is known the most sensitive (resonance) spectral lines of these elements are in the Schumann zone. To excite the spectrum of sulfur, the latter was introduced into a channel, drilled in the cathode made of spectrally pure carbon; the phosphorus was introduced into the cathode in form of  $P_2O_5$  compound. In fig.9 is shown the sulfur spectrum obtained in such a way, photographed together with the cast iron spectrum on the SP-33 spectrograph at the following mode of operation of K.I.:  $C = 500 \mu_f$ ,  $V = 220$  v,  $L = 3 \mu$  henries. As we see in the spectrum of cast iron are no sulfur lines, to attain their development by changing the parameters of the K.I. discharge contour (increase in L) was impossible for us. The same thing can be said with respect to phosphorus.

#### Breaking Condensed Arc in Vacuum

To raise the temperature of vacuum arc we tried to pass through it current pulses using for that a battery of high capacity capacitors. Such a source should differ by intensive inflow of electrode substance into the discharge and by high temperature. However after each discharge pulse the vacuum arc died out. This very same effect has been observed by I.I.Levintov [34] working with a DC arc in the air. To bypass this impediment the capacitor charge was used in combination with a breaking arc in vacuum. The very same discharge tube was used as in the job with the contact spark. The mushroom-like connection of the upper electrode holder allowed to roll this holder relative to the vertical axis. This movement, accompanied by approach and getting away of the electrodes, was connected with the operation of the electric switch (K) (fig.10) so that at the moment the electrodes made contact the capacitors were charged, and during the separation of the electrodes the vacuum arc became ignited, and when the distance between same reached a certain definite value, to them was auto-

matically connected the battery of capacitors, which by that time was already connected with the power circuit. The system was driven by one collector type electric motor (small motor), having a revolution reductor. The oscillation frequency of the upper electrode was regulated by changing the resistances in the power circuit of the little motor and it constituted 1 - 3 c. To feed the arc and charge the capacitors was used a DC current with a voltage of 220 v. The battery of capacitors had a capacitance of  $500 \mu\text{f}$ . Autoinduction of the feeder line wires in the discharge circuit was about 3  $\mu$  henries. In fig.11 is shown the spectrum of breaking condensed arc between aluminum electrodes, obtained at above mentioned conditions with the aid of a fluorite spectrograph SP-33.

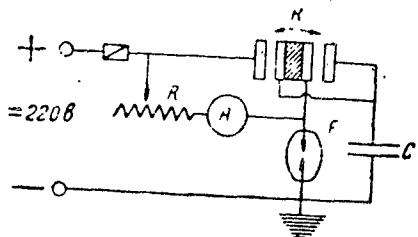


Fig.10. Electric diagram of breaking condensed spark in vacuum.



Fig.11. Spectra between aluminum electrodes:  
a-for breaking vacuum arc; b-for breaking  
condensed arc

Along side (fig.11,a) is given the spectrum of a breaking arc between the very same electrodes, photographed at an average current of 3 amp. Exposure in first case was 50 pulses. On the first photo are visible very intensive lines of ionized aluminum Al III, while they are almost totally absent on the second. Analogous spectra have been obtained with electrodes made of other metals.

#### Conclusions

1. Stable vacuum arc can be obtained at relatively low currents (5-7 amp) between carbon and graphite cathode and anode made of any given high melting metal by smoothly separating the electrodes. The arc burns stably at a small interelectrode interval of the magnitude of 1 mm, in the vacuum ultraviolet zone are excited almost exclusively the carbon lines.

2. Stable vacuum arc at currents of 5-7 amp between the carbon cathode and metallic anode can be obtained by rapidly separating the electrodes to a distance of 3-5 mm, provided on the DC current is applied a high frequency high voltage.

3. A new source has come to realization: contact spark - low voltage spark between two weakly contacted electrodes, one of which is a carbon one, originating during the discharge of a high capacitance capacitor. Contact spark can work in the air and in high vacuum as well. In it is developing a temperature, sufficient to excite spectra of repeatedly ionized atoms.

4. By combining breaking vacuum arc with capacitor discharge was brought into realization a source of vacuum ultraviolet, having intensive evaporation of electrode material and high temperature - breaking condensed arc.

In conclusion I want to express my thanks to F.A.Korolev for cooperation and assist, given to me in preparing this report.

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